A Study of an UWB Hospital Environment for a Bodyworn Antenna

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*Abstract***— For the first time, this paper presents both static and mobile signal strength measurements made for a bodyworn UWB radio channel in a 49m^2 hospital environment using RF-over-fibre technology to eliminate unwanted electromagnetic interference effects associated with the use of RF co-axial cables. The results show that received signal strength values depend significantly on whether the transmit and receive antennas are in relative LOS or NLOS, with LOS values being higher than the reference value and NLOS being less than the reference value. For mobile tests, LOS conditions tended to be either Rice or Gamma distributed with NLOS Lognormal distributed. For static conditions, signal strength is also dependant on user mode, with the difference between standing and sitting in the same location being up to 10.66dB.**

I. INTRODUCTION

The cost of health care continues to rise, as does the average age of the western population; these factors are putting a strain on the clinical resources of most western countries. Medical institutes are considered to be 10 years behind other big businesses in the effective utilisation of technology [1]. However, it is envisaged that reliable high speed mobile wireless data access has become a fundamental aspect of modern and future health care [2].

The traditional method to monitor patients involves placing sensors on the patient's body and connecting these sensors via wires to various electronic devices which process and display the data. On occasion these wires between patient and machines can complicate treatment and makes it difficult to transport patients without an interruption in monitoring [3]. However, replacing these wires with a robust wireless connection allows patients an increase in mobility and comfort [2]. Wireless connectivity involves a potentially complex body sensor area network and wireless link between the network and a hospital base station.

Wireless Sensor Networks (WSN), of consist of tiny, low power, real-time embedded systems (Motes) placed around the human body and are used to record and relay physiological data including vital signs, such as respiratory rate, oxygen saturation, electrocardiogram, heart rate, etc [3].

Multiple sensors connect with each other in an ad-hoc body area network (BAN), and then ultimately with the Mote processor device; which acts as the gateway from the BAN to the hospital network. Once into the hospital network the patient's data can be processed and displayed to the attending clinicians. Sensor networks can thus be utilised for monitoring vital signs and kinematics of a patient and provide real-time data to medical personnel [1].

Transmission of data from the mote processor to the hospital network is a key topic that has attracted must interest [4]-[7]. It is clear from this recent research work that various wireless data transmission technologies can be used, including Wi-Fi, Bluetooth, UWB, Zigbee, etc, with many commercial devices opting for Bluetooth [1], [8].

UWB has been highlighted as a possible technology solution for areas less than 15m, boasting very low power, cost and complexity and very high data rates [9]. In tele-medicine UWB would be suitable for transmitting sizable volumes of streamed patient data within indoor hospital environments as it is less affected by multipath environments, NLOS scenarios and pedestrian traffic, than other competing technologies. Bandwidths for vital signs data a generally large and UWB would easily meet these needs [3], [10], [11]. It is thus suitable for a busy ward with doctors, patients, nurses and visitors blocking the LOS path between transmitter (Tx) and receiver (Rx) [12]. It is also hospital safe and will not impinge on other wireless systems [2].

FCC has allocated 7.5 GHz of spectrum for unlicensed use of UWB devices in the 3.1–10.6 GHz frequency band with devices subject to controlled power and frequency limitations. The FCC defines an UWB radio system as occupying a bandwidth greater than 20 % of the central frequency or an absolute bandwidth greater than 500 MHz [13].

Currently only a few studies have addressed the topic of UWB radio links in hospitals [14] and some have considered bodyworn units [10], [14], [15]. However, to date, no study has been conducted on the analysis of a hospital environment for an UWB wireless Personal Area Network is presented for the first time.

For antennas worn against or close to the body, radiation patterns can be distorted due to coupling effects, causing signal attenuation and antenna detuning [16]. Hence, characterisation of the UWB radio channel for specific environments and user modes is essential to develop an understanding of future systems and design challenges. The purpose of this paper is to report on the characterisation of a bodyworn UWB radio channel for a hospital environment. Section II describes the measurements system utilised, the environment and the test procedure. Section III reports on the experimental results, Section IV highlights conclusions.

II. Measurement System, Environment and Procedure

A. System

A bodyworn measurement system consisting of a single UWB antenna fed by a bodyworn battery powered UWB PulsON source using 1550 nm RF-over-fibre to guide the signal from the FCC compliant PulsON source to a bodyworn UWB Fractus antenna; Figure 1 depicts the layout. The RF-over-fibre technology is implemented to eliminate electromagnetic interference effects associated with electrical cables; ensuring spurious electromagnetic effects are not confused with genuine channel characteristics. The transmitted signals are received by a PulsON UWB Rx using a PulsON UWB antenna. A laptop running PulsON software records received data at a rate of 100 samples per second.

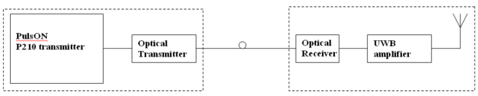


Fig 1: Transmitter diagram

System Specification includes an f_c of 4.7 GHz, bandwidth of 3.2 GHz and a launch power of -43 dBm. The sample rate of the system meets Nyquist frequency requirements. Doppler frequency due to a mobile transmitter, which at 6GHz for a node moving at 0.5m/s is 10Hz; the rate for data capture is 100Hz.

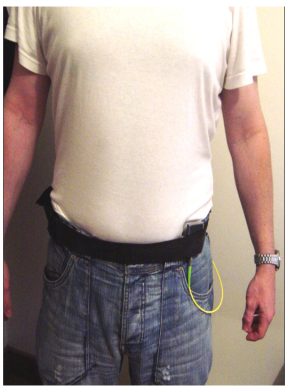


Fig 2: picture of patient wearing the equipment

Figure 2 depicts the body-worn transmitter in a waist-worn configuration. The antenna is held against the body using an adjustable cloth elastic band to minimise body-antenna separation during testing

B. Environment

The measurement system campaign was undertaken in a specialist nursing training room in University of Ulster at Coleraine in Northern Ireland. This 49m^2 training room faithfully recreates a real hospital ward and is fitted with NHS specification beds, rails, bedside cabinets, etc. The building was of 1960s construction, consisting mainly of double concrete-block cavity external walls, single brick internal walls and concrete floor. The ceiling supports luminaries suspended 2.8 m above floor level. This would be in keeping with many established hospitals in the UK.

C. Procedure

The receiver is placed above an entrance door at a height of 2.2m to replicate a base-station access point. The measurement system periodically records the channel impulse response (CIR) of the transmitted UWB signal. A reference signal strength measurement was recorded for a direct line of sight scenario for Tx-Rx separation of 3.2m in an anechoic chamber. This reference value is considered as an ideal link scenario to which all others can be compared. Tests are split into 2 categories; static and mobile measurements.

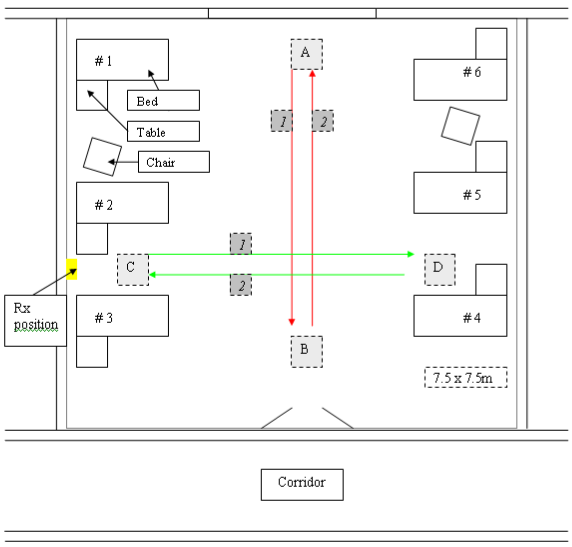


Fig. 3: Equipment in use (single antenna shown

1) *Static tests - Tx on waist recorded at position #2 and #6;*

- Patient/clinician standing beside bed
- Patient/clinician sitting in chair
- Patient sitting in bed
- Patient lying (face-up) in bed

2) <u>Mobile tests</u> - Adult male, 82Kg, 180cm, speed =0.5m/s, Tx on waist.

- Patient/clinician mobile A to B (LOS – red path 1)
- Patient/clinician mobile B to A (NLOS – red path 2)
- Patient/clinician mobile C to D (LOS – green path 1)
- Patient/clinician mobile D to C (NLOS – green path 2)
- Patient/clinician moves without restriction.

The tests of a person in bed clearly only refer to a scenario of a patient wearing a Wireless Sensor Network, however, the other tests could be considered appropriate for both a patient under treatment, or a clinician wearing a transceiver to collect data from the patients under his/her care. Post experiment signal processing using Matlab is employed to extract the signal strength data from the recorded files.

III. Results

The measurements were file captured at the PulsON receiver with use of a notebook running PulsON software. The captured files were processed using Matlab. All tests were repeated multiple times to ensure accuracy and statistical significance.

A. Static results

Results were conducted as outlined above. Results show the standing position ensures the highest signal strengths, with the lowest coming from the seated position. This is due to the seated position portraying increased body-shadowing effects, increased Tx/Rx height differential and also signal blocking due to the metal beds between the seat and the receiver. It is also observed that sitting upon the bed reduces the signal strength to a degree, however lying down has a marked effect on signal strength for the same location. This is essentially caused by the change in orientation of the transmitter antenna with respect to that of the receive antenna. It is also noted that the mean signal strength at position #6 is higher than at #2. This is related to better positioning in the receive antenna's bore site. These results are recorded in Table 1.

Ward location	Patient position	Signal strength w.r.t. reference (dB)
#2	Standing	-2.56
	Sitting (chair)	-13.22
	Sitting (bed)	-3.17
	Lying (bed)	-11.23
#6	Standing	0.42
	Sitting (chair)	-9.31
	Sitting (bed)	-0.46
	Lying (bed)	-7.33

Table 1. Signal strength results for experimental tests

B. Dynamic

Graphs of cumulative density function (CDF) are presented for each of the 5 tests. A graph of relative received signal strength w.r.t. time for the A to B journey is shown to describe an example of the recorded results. For the CDF the signal strength data was organised into bins according to the Freedman-Diaconis rule. Results of the CDF are compared to theoretical statistical distributions as a basis for mathematical modelling of the radio channel.

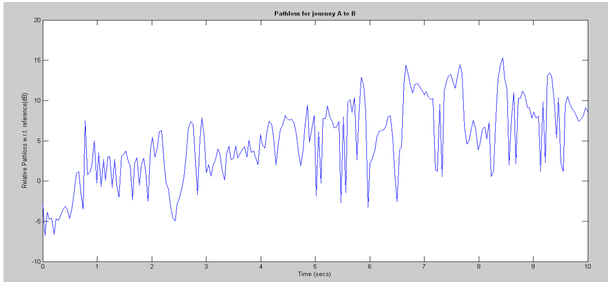


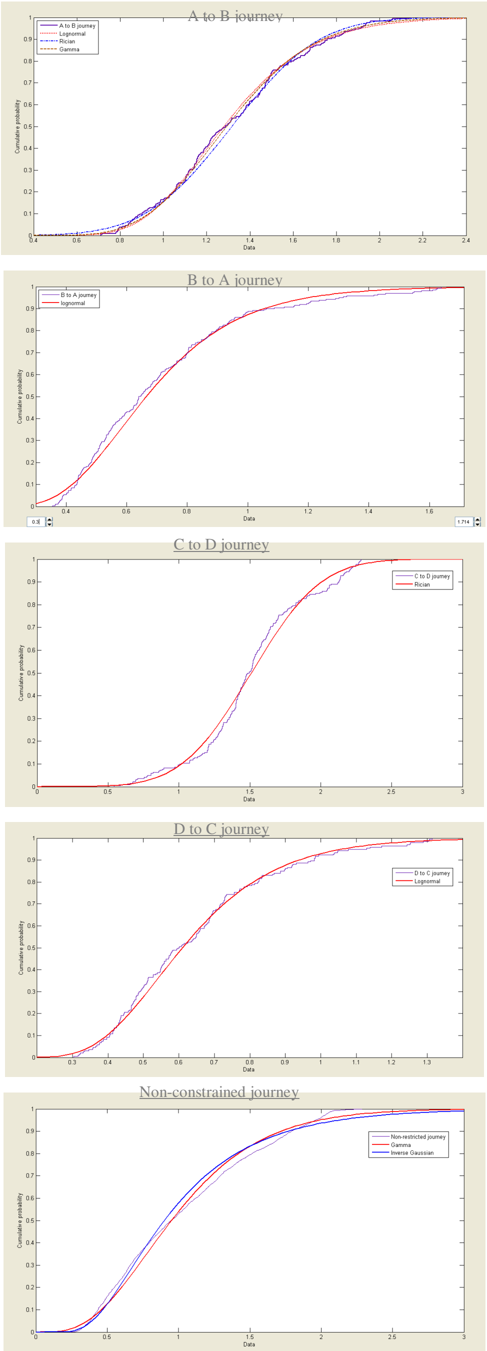
Fig 4: example relative received signal strength w.r.t. time

The LOS journey from location A to B shows an increase in mean signal strength as the transmitter and receiver distance is reduced; this is in keeping with theoretical predictions [2]. The CDF was compared to 3 theoretical distributions; Rician, Lognormal and Gamma. Each of the three offered a good fit, but statistically the Gamma distribution was concluded as the best fit. The B to A journey was assumed a classical NLOS scenario, and as such should be suitably modelled by the Rayleigh distribution [17]. However, in this multipath NLOS environment, the UWB channel was best described by the Lognormal distribution.

C to D journey correlated well with the Rician distribution, an accepted model for small-area fading in the presence of a single dominant specular component is the Rician distribution model (LOS) [18]; a scenario suitably depicted in this close range LOS test. D to C journey, an NLOS scenario, depicted Lognormal distributed data, as per the previous NLOS test from location B to A. CDF for the non-constrained journey were Inverse Gaussian distributed; this distribution is sometimes referred to as the Wald distribution.

Journey	Distribution	Mean	Variance
A to B	*Gamma*	*1.31771*	*0.100482*
B to A	*Lognormal*	*0.709202*	*0.0690065*
C to D	*Rician*	*1.51172*	*0.147786*
D to C	*Lognormal*	*0.645653*	*0.049863*
Non-constrained	*Inverse Gaussian*	*1.03341*	*0.320715*

Table 2. Mean and variance measurements for each mobile test



Figs 5-9: CDF of relative received signal strength for mobile tests

IV. CONCLUSIONS

For the first time, relative signal strength results for both static and mobile signal strength measurements made for a bodyworn UWB radio channel in a 49m^2 hospital environment using RF-over-fibre technology have been presented. Experimental results have shown that for mobile tests, LOS conditions tended to be either Rice or Gamma distributed and NLOS Lognormal distributed. Static experiments have highlighted that signal strength is dependent on user mode as well as the multipath hospital environment. To date, this equipment and conducted work is the only off-body propagation work which removes the RF effects of the co-axial cables.

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